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United States Air Force Research Laboratory

Pilot Study: System Model of Situation Awareness: "Sensemaking" and Decision Making in Command and Control

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March 2004

Interim Report for the Period May 2003 to March 2004

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NOTICES

TECHNICAL REVIEW AND APPROVAL

AFRL-HE-WP-TR-2004-0071

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

//Signed//

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Chief, Warfighter Interface Division
Air Force Research Laboratory

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 2004	Interim - May 2003 - March 2004

4. TITLE AND SUBTITLE
Pilot Study: System Model of Situation Awareness: "Sensemaking" and Decision Making in Command and Control

5. FUNDING NUMBERS
C: FA8655-03-1-3041
PE: 62202F
PR: 7841
TA: 10
WU: 01

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory, Human Effectiveness Directorate
Warfighter Interface Division
Air Force Materiel Command
Cognitive Systems Branch
Wright-Patterson AFB OH 45433-7604

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-HE-WP-TR-2004-0071

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

"Sensemaking" has emerged as an organizing construct, which reflects the key ideas of warfighting in the cognitive domain. This Pilot Study explores the relationships between "sensemaking", decision making, and situation awareness in the context of command and control requirements.

14. SUBJECT TERMS
Sensemaking Decision Making Situation Awareness Command and Control

15. NUMBER OF PAGES
62

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

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Preface

The current pilot study deals with the representation of uncertainty in C^3I information (Situation Awareness) systems, which are regarded as partial representations of real-world objects and events. Decision makers may face uncertainty due to individual circumstances. However, much uncertainty results from the limited ability of C^3I information system to fully represent real-world objects and events. For the commander, this uncertainty constitutes a baseline to which we refer as *basic uncertainty*. In the pilot study we review related literature, propose new ways for categorizing uncertainty, discuss possible methods for attenuating the negative effects of uncertainty and propose further research.

This material is based upon work supported by the European Office of Aerospace Research and Development (EOARD), London, England under Contract Number FA8655-03-1-3041. Lt Col, Valerie E. Martindale, Chief, Life Science and Human Effectiveness, was the contract monitor. Mr. Gilbert Kuperman of the Air Force Research Laboratory's Human Effectiveness Directorate (AFRL/HECS) served as the contracting officer's technical representative.

The authors wish to thank Lt. Col Martindale for her support and to Mr. Gilbert Kuperman for his support, guidance and invaluable contributions throughout this study.

Abstract

In recent years military forces have been striving to adapt network centric, information superiority-enabled warfare concepts (Leedom, 2001). One of the practical implications is the development of technology for acquiring, processing distributing and displaying battlefield information. Command, Control, Communication and Intelligence (C^3I) information systems are gradually deployed to all operational levels, from the highest command echelons to individual shooters. It is argued however, that despite these developments, the level of uncertainty in the battlefield may not be much lower than it was in the past.

The present report deals with the representation of uncertainty in C^3I information (Situation Awareness) systems, which are regarded as partial representations of real-world objects and events. Decision makers may experience uncertainty because of insecurity, lack of experience, etc.; much uncertainty, however, results from the limited ability of C^3I information system to provide full and accurate representations of real-world information. This uncertainty constitutes a baseline to which we refer as *basic uncertainty*.

The term "information world" is used to describe the real-world information that a commander or a command team need during various stages of a representative C^3I mission. This information is the basis for decision making which, most often, takes place under highly stressful conditions. The human operator is unable to directly acquire real-world information and has to rely on information that is symbolically represented by C^3I information systems, which is inherently partial and inaccurate (i.e., uncertain).

The cognitive concepts of Situation Awareness (SA), Sensemaking and Naturalistic Decision Making (NDM) have developed during recent years in an effort to gain better psychological understanding of human operation and performance in real-world situations, particularly, situations that involve complex, human-machine systems. These theoretical frameworks are used to analyze the C^3I environment and C^3I information systems. Two methods for sorting uncertainty in C^3I are presented: *sorting by source* and sorting by *level of uncertainty*. First, sorting by *sources of uncertainty* which may be technology related (acquisition, processing, and display systems) or user related (experience, confidence, etc.), where system related sources are defined as *basic uncertainty*. Second, sorting by the *level of SA*, Perception, Comprehension or Projection (Endsley, 1995), that is supported by the

information. Then we analyze various methods of coping with uncertainty, focusing primarily on *basic uncertainty*. *Basic uncertainty* may sometimes be reduced by improving information quality and representation techniques, however, the focus of this study is on how to deal with information about *uncertainty*; what are the pros and cons of presenting or not presenting the user with information about known sources of *basic uncertainty*. Some possible approaches and techniques for coping with the *remaining uncertainty* and attenuating its negative consequences are presented.

Finally, ideas for further research, focusing on the representation of *uncertainty*, are outlined and briefly discussed.

Contents

Introduction

The technology for acquiring, processing, distributing and displaying battlefield information is constantly developing. The military forces are striving to parallel the information revolution in the commercial sector by adapting network centric warfare concepts (Leedom, 2001), defined as "an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision-makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability and a degree of self-synchronization" (Alberts, Garstks & Stein, 1999). C^3I information systems are actually being developed in the framework of several ongoing projects. For example, the US Army FBCB2 system (Talcott, Martinez, Bennet, Stansifer & Shattuck, 2001); the Lockheed Martin contract to develop a Joint battle-space situational awareness capability designed to serve as the primary common operational picture for all four military services (Lockheed Martin, May 6, 2003); MAGIS - Marine Corps Air Ground Intelligence System (Intelligence Department Headquarters, UA Marine Corps, 2003); The USAF "Cyber Warrior" information system (Kuperman, Whitaker & Brown, 2000).

Winning the information war may be the key to victory in war (Kuperman, 2001). On the other hand, lack of information or unreliable information can break the command and control process and disrupt any offensive initiative, causing one's forces to remain one step behind the enemy (Flach & Kuperman, 2001).

As an important part of the concept of information superiority, C^3I information systems that previously had been used only by high levels of command or on board major weapon systems (e.g., bombers), are gradually being deployed to the shooters' level (Leedom, 2001). Despite these developments, however, the level of uncertainty in the battlefield may not be much lower than it was in the past. The modern battlefield may contain a greater than ever number and variety of objects, many of which may be dynamic. In terms of the US Army 'cognitive hierarchy' (Headquarters Department of the Army, 1996, from Kuperman 2001, p. 232) C^3I systems may support the levels of *data* and *information* but may not contribute much to *knowledge* and *understanding.*

Figure 1 presents a schematic illustration of this notion.

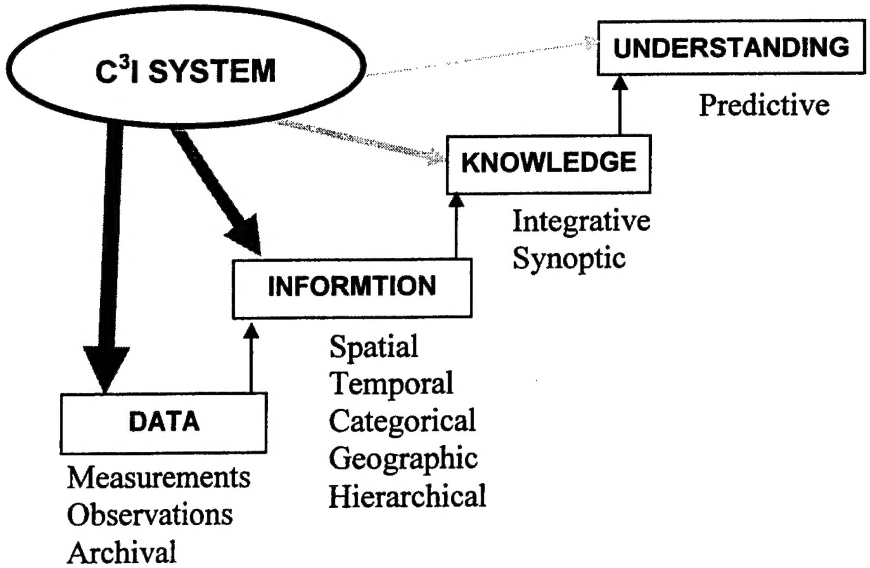

Figure 1: The C^3I information system may provide ample amounts of high quality *data* but less *information, knowledge* and *understanding*. The width of the line symbolizes quantity and its darkness symbolizes reliability (e.g., there may be much reliable *data* but only little and unreliable support for *understanding*).

The present report deals with the representation of uncertainty in C^3I information systems.

An interim report titled "Pilot Study: System Model of Simulation Awareness and Decision Making in Command & Control – Workplan, presented the main concepts that were elaborated and developed in this report (see Appendix A). A C^3I decision maker may experience uncertainty because of insecurity, lack of experience, etc. Much uncertainty, however, results from the inability of C^3I information systems to provide a full and accurate representation of necessary information. This uncertainty constitutes a baseline to which we refer as *basic uncertainty*.

The next section presents some of the circumstances under which commanders make decisions: their "information world", the nature of C^3I information systems and some initial notions regarding the representation of uncertainty.

The "information world" and its representations

The "information world" of the commander

Commanders plan, command and control missions that take place in the real world. The term "information world" is used to describe the combined sources of information that are necessary for the performance of these tasks. The "world" can be divided into four dimensions:

- The physical world (geography, atmosphere).
- Friendly forces (command levels, commanded forces, own unit, other units, neutral forces).
- Enemy (sites, targets, threats).
- Mission stages (planning/rehearsal, mission performance, debriefing).

Table 1 presents an example of the possible components in the information world of a commander or a command team, in a C^3I aerial strike command center (i.e., an air operations center). Based on Endsley's (1995) definition of situation awareness, (see next section - "Theoretical background") it may be useful, for some information elements, to indicate the necessary levels of commanders' knowledge: Perception (detection, recognition and identification of major features); Comprehension (significance, intentions, capabilities, etc.); and Projection (Where will it be? and What will it be doing in the near future?).

Table 1: Example of elements in the "information world" in a C^3I aerial strike command center.

Type of information			Level of knowledge		
Category	**Details**	**Example**	**Perception**	**Comprehension**	**Projection**
Geographical space	Terrain	Hills, mountains, valleys, etc.	Flying altitude	Threat exposure	
		Obstacles	Route, altitude		
		Airfields	Location, capacity		Emergency landing
		Waypoints	recognition	Significance	next
	Lines	Boarder	Location	Threat	distance
		Enemy lines	Location	Threat	distance
	Aerial space	Routes	Location	Relative location (other elements)	Rate of projected changes
		limitations			
Time and atmosphere	Time	Day / night	Visibility, use of sensors & devices	Visibility limitations	Detection / Recognition ranges
	Weather	Winds			
	Visibility	Fog, haze			
Friendly forces	Superiors	Headquarters	Orders	Intentions	expectations
	Subordinates	Strike formations	Status	Capabilities	Conduct
	Support	Electronic warfare	Status	Effects	Future effects
	Other friends	Other formations	Location	Role in mission	Future status
		Ground forces	Location	Effects on mission	Future effects
	Neutral forces	Civilians,	Location	Significance	Future status
		UN forces			
Enemy	Sites	SAM sites	Location	significance	Future status

Type of information			Level of knowledge		
Category	**Details**	**Example**	**Perception**	**Comprehension**	**Projection**
	Deployment	Mobile SAM			
	Targets	SCUD launchers	Location recognition	Hit probabilities	Future status
	Aerial threats	Enemy fighter aircraft	location	Level of threat	Future status
	Ground threats	SAM	location	Level of threat	Future status
Mission stages	Planning	Monitor intelligence	Relevant items	Significance	Effects on mission
		Plan mission			
		Prepare & distribute orders			
	Command & control	Monitor forces	Location status	Significance	Effects on mission
		Refresh commands			
		Compare to planning			
	Debriefing		(not in scope)		

Stress and ucertainty in the commander's world

Battlefield command is often associated with severe stress, much of which may be related to decision making under uncertainty. In the battlefield, decisions may determine matters of life and death and making such decision on the basis of imperfect information (i.e., uncertainty) may be very stressful. (Leith, 2003).

The commanders are at the focal point of operational activities. They communicate with their superiors, coordinate with peers and command their subordinate forces. Intensive activities and tight schedules impose high workload. Commanders may not have the time and mental resources for small details; hence, they may be able to use existing information

only if it is clear, readily available and properly designed and displayed (Pascual & Henderson, 1997; Flach & Kuperman, 2001).

Representation of the information world in C^3I systems

Commanders who operate in headquarters or air operations centers do not have direct access to real-world information. Instead, they must rely on information that is acquired in the real world by various devices, processed by humans and computers, distributed via communication networks and presented on C^3I information systems.

A typical C^3I information system may contain some or all of the following capabilities:

- The basic display may consist of some type of map or aerial photo that contains three-dimensional terrain information.
- A variety of maps, of various scales, and supported by pan and zoom capabilities to enable different views.
- It may also be possible to analyze the terrain (e.g., compute lines of sight), analyze flight route, assess "trafficability," etc.
- On top of the map, various layers of information may be displayed, e.g., enemy forces, friendly forces, sites, deployments, etc.
- The system may also be used for mission planning, e.g., monitoring intelligence, viewing raw data (e.g., UAV videos), preparing flight plans, preparing mission plans and orders, and distributing them via the communication network.
- In addition, the system may contain general information (e.g., the hierarchical structure of forces, alphanumeric intelligence, technical information, etc.).
- The systems are connected via data communication networks that enable each of the network members to view relevant information. Friendly forces may transmit to each other their location, status etc.; some users may also feed information into the system (e.g., online intelligence). The existence of similar enemy information depends on intelligence sources.

Representation and uncertainty

The flow of information is presented in Figure 2. Events take place in the real world and are captured and acquired by various devices. This information is processed, disseminated and displayed to the commanders or the command team, who employ various cognitive processes (described later in this report), make decisions and take action. Uncertainty exists all along the process; a distinction is made between *basic uncertainty* which stems from acquisition and display systems and *uncertainty* that is also affected by the limitations of the human decision maker (interpreted later in this report).

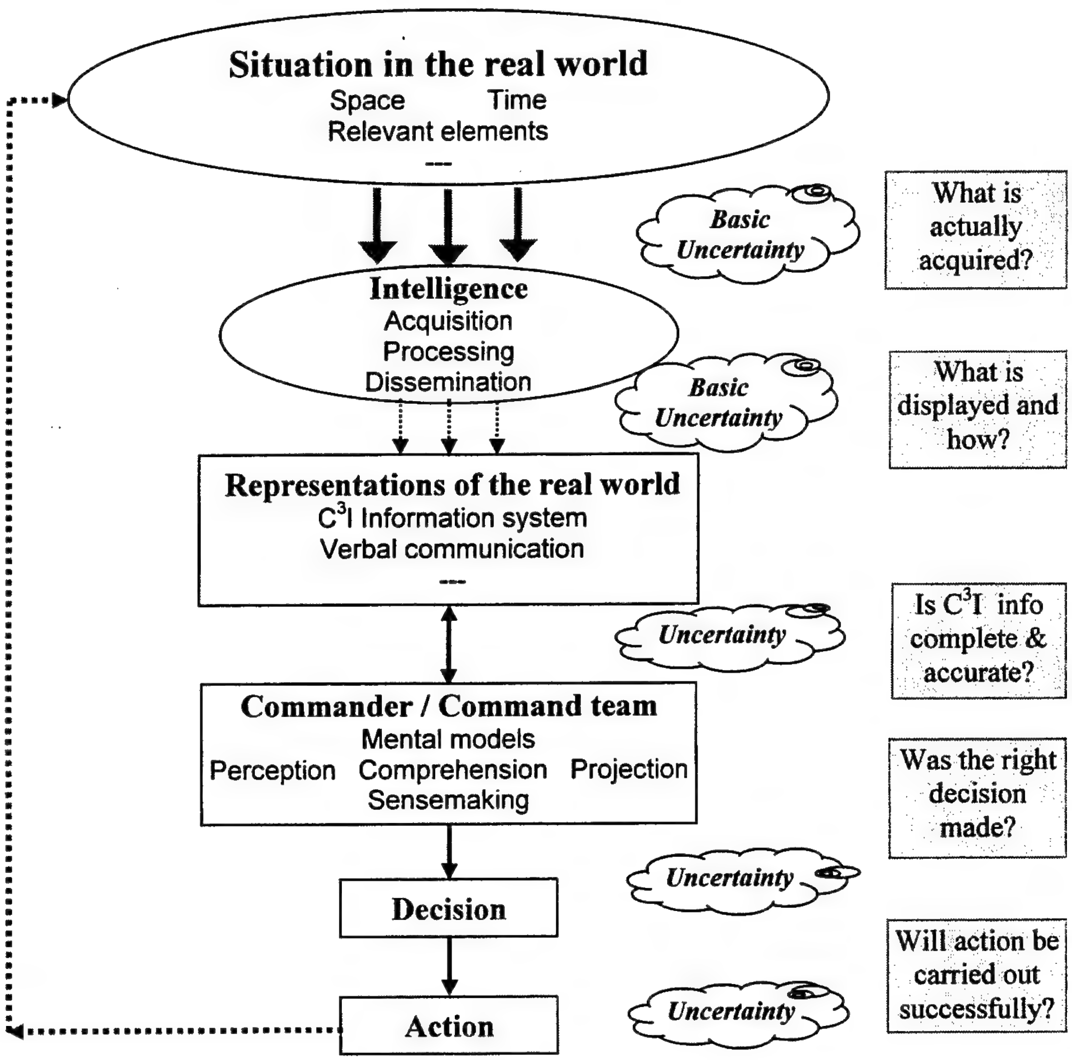

Figure 2: The flow of information from the world to the C^3I system and to the commanders who make decisions and take actions (see text for further interpretation).

This model is somewhat similar to a model that was recently presented by Miller & Shattuck (2004). These authors distinguish between technological systems (including, data in the environment, data detected by systems and data available in C^2 system) and the perceptual and cognitive processes (including data, comprehension and projection). Their model emphasizes the available information (i.e., SA) rather than the missing information (i.e., uncertainty).

In this section we analyzed the real-world information that a commander or command team needs during various stages of a representative C^3I mission. This information is the basis for decision making that may take place under highly stressful conditions. The human operator is unable to directly acquire real-world information and has to rely on inherently partial and inaccurate (i.e., uncertain) information that is symbolically represented by C^3I information systems. As a result, commanders' decisions are affected by various types and sources of uncertainty that were described as *basic uncertainty* or as *uncertainty*.

In the next section we present the theoretical background for the cognitive analysis of decision-making in highly complex C^3I situations.

Theoretical background

This section focuses on three integrative theoretical concepts: Situation awareness (SA), Sensemaking and Naturalistic Decision Making (NDM). These concepts have evolved in recent years and provide tools for research and analysis of complex human-machine systems.

Situation Awareness (SA)

SA is a theoretical concept that enables the description and analysis of whole situations. The concept may be useful if based, consistently, on a clear definition (Pew, 2000). Endsley (1987, 1995) proposed a widely accepted definition of SA as "the Perception of the elements in environment within a volume of time and space, the Comprehension of their meaning and the Projection of their status in the near future". This definition applies well to physical environments (space, ground, air) and is useful for the analysis of human activities in dynamic physical environments (e.g., command and control).

Endsley's characterization of the components of the SA definition is task dependent and is based on examples. The following is the proposed interpretation of these components in the context of C^3I:

Situations: Continuous activities within a scenario may be viewed as a chain in which each link is a *situation.* One situation lasts as long as changes in the scenario are moderate and continuous; whereas large, discrete changes may require the classification of a new situation. For example, the transition from the planning phase to the mission performance phase in C^3I is bound to create a new situation; during mission performance, various changes and transitions may also delineate different situations (e.g., fighter aircraft takeoff, navigation, air-to-ground attack, aerial combat and landing).

Space: The C^3I environment is about real physical space (ground, air, sea) in which action takes place.

Time: Time affects the dynamics of the situation (e.g., rate of change) and is crucial for Projection (How much time has passed? How much is left? Where will element X be in t seconds?); in addition, timing determines the coordination of multiple elements.

Relevant elements: The relevance of objects is determined by the situation, the mission and the operator's tasks. Examples of objects that are relevant to C^3I information systems were presented in Table 1 above.

Perception: It is suggested that Perception refer to the main physical attributes of objects including detection, recognition and identification of primary features (e.g., movement).

Comprehension: In the present context, Comprehension refers to the understanding the significance of objects and events (e.g., Does it pose a threat? What is the operational significance of a specific deployment?).

Projection: Projection of the status of elements in the near future may be related to movement, motion (within object) or other changes (e.g., status, resources, capabilities, priorities, motivation). Projection reflects the notion that, most of the time, the scenario evolves continuously and regularly and, consequently, events are more or less predictable.

SA is only one of the mechanisms that take part in decision making and performance processes. Endsley (1995) suggested that SA is primarily affected by the environmental situation but also by task and system variables (e.g., system features, user interface, stress and workload); by knowledge (long-term memory, mental models) and by goals, intentions and expectations. SA affects decision making which, in turn, affects performance that feeds-back into the environmental situation and so on. The whole process consumes attention resources and relies heavily on working memory.

It is widely accepted that in order to be effective, the knowledge base that enables SA must be well organized. These organizations are referred to as mental models (Rouse & Morris, 1986; Mogford, 1997; Wilson & Rutherford, 1989; Endsley, 2000), as schemata (Lipshitz & Ben Shaul, 1997) or as frames (Klein, Philips, Rall & Peluso, in press). It should be noted that a commander may have to employ several cognitive processes in order to handle

the many types of incoming information and construct a consistent mental model. It may be necessary, for example, to perform spatial extrapolations in order to project the future location of objects (Cooper, 1989); perform mental rotations in order to recognize objects from non-prototypical perspectives (Shepard & Metzler, 1971); "translate" verbal information about spatial objects into spatial representations; and integrate information from various sources and modalities into a coherent model. The commander's mental model of the battlefield may have dominant spatial and visual features that may rely on "visual thinking" or "using vision to think" (Card, Mackinlay & Shneiderman, 1999).

SA in C^3I information systems

The analysis of the *information world* of a commander in terms of the SA levels of Perception, Comprehension and Projection (Table 1), demonstrates how the concept of SA can contribute to the understanding of the C^3I environment. Several researchers have investigated C^3I in terms of SA (e.g., Kaempf, Klein, Thordson &Wolf, 1996; Endsley, 2000; Entin & Entin, 2001).

SA is crucial for command and control (e.g., Wickens, 2000; Rodgers, Mogford & Strauch, 2000; Matthews & Shattuck, 2001). In view of Endsley's (1995) definition of SA - events take place within the physical volume of the real, three-dimensional space and evolve in time - the commander must be aware of several types of relevant elements (Table 1), and must perceive, comprehend and project their future location and status.

As indicated above, the real world cannot be viewed directly; therefore, commanders' SA depends on various representations of the world, including the C^3I information system, verbal communication and other sources (e.g., sensor imagery). Later in this report we examine how well these representations may support commanders' SA.

Sensemaking

Endsley's (1995) definition of SA is limited to perception, processing and understanding of data and information and does not deal with decision making and performance processes. *Sensemaking* is a broader concept that addresses these issues. In addition, Sensemaking is more strongly oriented towards team and even organizational processes (even though team

SA has also been addressed, e.g., Salas, Prince, Baker & Shrestha, 1995; Endsley & Jones, 2001). Moreover, Endsley's notion of SA tends to view the process of building and maintaining SA as a somewhat passive response to the situation, whereas Sensemaking is explicitly viewed as a conscious and active process. (e.g., Louise Comfort, in Leedom, 2002; Klein, Phillips, Rall & Peluso, in press).

The concept of Sensemaking was discussed in two recent meetings of invited experts (Leedom, 2001, 2002). A wide variety of subjects was presented, including: development and maintenance of SA by teams of system operators, pilots and other military crews; Sensemaking structure and processes in organizations; factors that enhance or suppress Sensemaking in organizations during crisis, transition, and risk management; the knowledge structure and the tools needed for the solution of complex problems by interdisciplinary teams of experts.

Klein *et al.*, (in press) proposed a comprehensive theory of Sensemaking. The authors view Sensemaking as a set of processes that is initiated when a person or an organization recognizes the inadequacy of the current understanding of events. Sensemaking may be a response to surprise or failure of expectations. Klein *et al.*, (in press) refer to 'mental model' as long term scripts and scenarios that have been learned and as causal mechanisms that explain how things work. The term *frame* is used to describe transient or ongoing processes. The frame is somewhat similar to situation assessment (Endsley, 1995) in that it is a hypothetical construct for examining and adapting the understanding of the world and the state of events. Sensemaking is an active process of fitting data into a frame and fitting a frame around the data. Neither the data nor the frame come first, the data evoke and help to construct the frame and the frame defines, connects and filters the data. When the data or the frame seem inadequate, data can be fitted to the frame or the frame itself may be questioned, elaborated, compared to alternative frames, changed or replaced.

Klein *et al.*, (in press) present characteristics of Sensemaking that may contribute to the understanding of C^3I information systems, as presented in the next section.

Sensemaking in C^3I information systems

The Sensemaking symposium (Leedom, 2001) was initiated by the Command and Control Research Program (CCRP) which identified Sensemaking as an essential cognitive element of the military decision making process. Three major needs were identified:

- First, the current and future need for broader and more complex spectrums of operations.
- Second, in response to the new spectrum of operation, employ new, more appropriate operational concepts and command approaches, e.g., effect-based-operations are replacing historic models of attrition warfare.
- Third, paralleling the information revolution in the commercial sector by adopting network centric warfare concepts, as opposed to platform-centric warfare. "An information superiority-enabled concept of operation that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability and a degree of self-synchronization" (Albert, Garstka & Stein, 1999).

Clearly, C^3I information systems constitute a major link in the information superiority-enabled concept (Flach & Kuperman, 2001).

Presently, however, Sensemaking is a fairly general concept which provides few specific models and research tools. Klein's *et al.*, (in press) Data/Frame theory of Sensemaking provides some heuristics, useful concepts and initial analysis tools.

Klein *et al.*, (in press) outlined twelve major characteristics of Sensemaking, several of which seem relevant to the operation of C^3I information systems (presented in parentheses below).

1. Sensemaking is a conscious and deliberate activity. (As are commanders' actions in the C^3I environment).
2. Sensemaking may be triggered by surprise or perceived anomaly. (Surprise and anomaly are part and parcel of the battlefield environment).

3. Sensemaking is the process of fitting data into a frame and fitting a frame around the data. (This model can be applied to the C^3I environment).
4. Data are inferred using the frame rather than being perceptual primitives. Because data are abstractions from the environment they are, potentially, distortions of realty. (The very nature of the C^3I information system imposes several of the distortions described by Feltovich, Spiro & Coulson (1997). In the complexity of the battlefield it is essential to perceive whole elements rather than numerous single events; continuous processes may be presented as discrete steps; dynamic processes may be presented as static ones; simultaneous processes are treated sequentially; complex systems may be conceived as simple casual mechanisms; interacting processes may be separated; etc.).
5. Data have to be distinguished from noise. (This is definitely the case in an environment which may contain decoys, destroyed targets, etc.).
6. The frame is also inferred based on a few key data elements that serve as anchors. (The complexity of the battlefield may require anchors for orientation and for the Comprehension of the picture as a whole, e.g., Wickens, Thomas & Young 2000).
7. The inferences used in Sensemaking do not conform to logical deduction. (According to Klein, *et al.*, information operations specialists rely on quasi-logical reasoning rather than on deductions; in other word, inferences tend to be more intuitive and are often a one-step process).
8. Experts in an area reason in the same way as novices (this is a general argument that, if accepted may applies to C^3I as well as to other areas).
9. Experts have a richer repertoire of frames and mental models. (This has been shown in many areas of expertise including C^3I, e.g., Serfaty, MacMillan, Entin & Entin, 1997; Lipshitz & Ben Shaul, 1997; Vicente & Wang, 1998).
10. Sensemaking is used to achieve functional understanding (what to do) as well as abstract understanding. (Clearly, both are necessary to the commander who has to take specific decisions whilst maintaining an overview of the situation as a whole).
11. Most of the mental models used by experts and novices are fragmentary. (Battlefield situations are often new and different from previous situations, hence, it may be hard to develop comprehensive mental models and the commander may have to rely on various ensembles of fragmentary models and frames).

12. The nature of Sensemaking varies depending on whether we are trying to size up a situation (i.e., assessment), build a richer understanding, raise questions about our understanding or explain away discrepancies, or compare different explanations or search for some explanation that can help us sort out what is going on. (This again is a general argument that relates to various environments and activities).

Decision making

In the chain of activities of a commander, or a commanding team, in the C^3I environment, decision making is the crucial link. The commander's ability is evaluated primarily by his/her decision making capabilities, even though, other abilities are important as well (e.g., leadership).

Lipshitz, Klein, Orasanu & Salas (2001) reviewed major trends in the history of decision making and the development of Naturalistic Decision Making (NDM). Lipshitz *et al.*, (2001) analyzed the differences between Classical Decision Making (CDM), Behavioral Decision Theory (BDT), Judgment and Decision Making (JDM) Organizational Decision Making (ODM) and Naturalistic Decision Making (NDM).

Rasmussen (1997) observed that in decision research (as well as in other human sciences) there is a trend of moving from normative models of rational behavior (e.g., CDM), through efforts to model the observed rational behavior (e.g., JDM), towards focus on representing the actual observed behavior (NDM) and ultimately which extends to modeling behavior-generating mechanisms such as system constraints, opportunities and criteria (e.g., ODM).

For several reasons, discussed below, NDM seems the most appropriate approach to the analysis of commanders' decision making in C^3I environments.

NDM

Lipshitz et al., (2001) delineated the main characteristics of NDM. Its applicability to the C^3I environment is outlined below.

<u>Proficient decision makers</u>: NDM views the decision making processes of experts as a focal point for research and investigation of decision making. In many important

respects this is contrary to the views of CDM, CDT and JDM which consider the level of expertise as nuisance variable (Pruitt, Cannon-Bowers & Salas, 1997). Obviously, military commanders, especially at intermediate levels of command, are formally trained to be proficient decision makers in the C^3I environment.

Field setting: Zsambock (1997) suggested that "NDM is the way people use their experience to make decisions in a field setting". The battlefield command post is a characteristic example of such a setting.

Process orientation: NDM models do not attempt to predict which option will be implemented, but describe the cognitive processes of proficient decision makers.

Situation-action matching decision rules: The study of proficient decision makers leads to modeling decision making as matching of a decision to a situation, rather than as choices between alternative decisions to the same situation. The time pressure and stress that characterize the C^3I environment suggest that at least during critical phases of the mission, examination of alternatives and the selection of the "best" one may be beyond the capacity of the decision maker (Simon, 1978). Several researches have identified situation-action processes in C^3I settings (Cohen, Freeman & Wolf, 1996; Pascual & Henderson, 1997; Drillings & Serfaty, 1997; Serfaty et al., 1997).

Context bound informal modeling: Proficient decision makers may be limited in their ability to use abstract formal models. For example, Pascual & Henderson (1997) found that during C^3I decision making, commanders were unable to use the Standard Operating Procedures of the British Army. Hence, NDM models depict what information decision makers actually attend to and which arguments they actually use, particularly in complex, real-world, decision making tasks (Cohen & Freeman, 1997).

Empirical based prescriptions: JDM and BDT derive their propositions from normative models that prescribe the "right" decision regardless of whether or not such decisions are likely to be taken in a realistic setting. As a result, the ability of these models to predict actual decisions in complex, real-life settings, are severely limited (Klein, 1999). In contrast, NDM derives its prescription from descriptive models of expert performance. The applied goal of such models may, for example, be to improve the

decision making processes of novice (less experienced) performers until they match experts' (more experienced) decision making. Many applied environments draw on the experience of experts rather than on soundly based theories. C^3I is certainly not an exception (Drillings & Serfaty, 1997), e.g., much of the curriculum of C^3I schools is based on the study of past wars and battles, on the personal experience of veteran commanders and on the analysis and practice of real and simulated battlefield scenarios (e.g., Lipshitz & Strauss, 1997).

Pascual & Henderson (1997) performed a C^3I simulation study with 32 subjects who had various levels of command experience. They analyzed the data in order to find which decision making model provided the best interpretation of their findings. The naturalistic strategies accounted for 87% of the variability, as compared to classical (2%), hybrid (3%) and "other models" (8%). The RPD model (Recognition-primed decision-making - see below) accounted for 60% of the variability, whilst the remaining 40% were divided between eight other models.

The RPD Model

The RPD (Recognition-primed decision – Klein, 1988; Klein, Calderwood & MacGregor, 1989; Klein, 1997), attempts to describe what people actually do under conditions of time pressure, ambiguous information, ill-defined goals and changing conditions.

The 1997 version of the model (Klein, 1997) distinguishes three levels of situations; its relevance to the C^3I environment is also indicated below.

- In the *Simple match* level, the decision maker experiences the situation in a changing context and perceives it as typical (prototype or analog). Recognition has four products: expectancies, relevant cues, plausible goals and typical actions – that lead to the implementation of a course of action. Simple matches are an important part of the routine of the C^3I environment (as well as in many other working environments). Much of the time the required action is easily selected based on the experts' experience and on sets of simple rules.
- In the *Diagnose the situation* level, the complexity lies in the diagnostic phase. The decision maker experiences the situation in a changing context, if it is perceived as

typical, the process proceeds as in the simple match. If not, a diagnosis may be made through feature matching or story telling. If necessary, the decision maker may seek for more data. Recognition has the same four by-products as in the simple case, however, if an anomaly is encountered the process may go back to the diagnosis phase. In the C^3I environment, difficulties in the diagnostic phase are an inevitable part of routine work, because, even the most advanced C^3I information systems leave much ground for uncertainty.

- In the *Evaluate course of action* level, complexity lies in the selection of action. Again, the process starts with the experience of the situation in a changing context that is perceived as typical. Again, recognition has the same four by-products (expectancies, relevant cues, plausible goals and action) in this case' however, more than one action may be possible; therefore, each of the alternative courses of action is evaluated through mental simulation and is either selected, rejected or modified. Finally, a course of action that is expected to work is selected and implemented. The evaluation of the adversary's possible courses of action and the preparation of appropriate reaction to these possibilities is part of the C^3I routine, especially during planning phases.
- Obviously, some decisions may require both the diagnosis of the situation and the evaluation of courses of action.

A critical assertion of the RPD model is that people can use experience to generate a plausible option as the first one they consider. This assertion, as well as other assertions of RPD has gained considerable empirical support in a variety of areas of expertise (e.g., chess - Klein, Wolf, Militello & Zsambok, 1995; Fire fighting – Klein, 1993; C^3I - Pascual & Henderson, 1997).

Coping with Uncertainty

Lipshitz & Strauss (1997) defined uncertainty, as "a sense of doubt that blocks or delays action". Using this definition, they identified three principle forms of uncertainty in retrospective reports on decision making under uncertainty: inadequate understanding (a sense of having insufficiently coherent situation awareness), lack of information (a sense of

incomplete, ambiguous or unreliable information) and conflicted alternatives (a sense that available alternatives are insufficiently differentiated).

102 students in a decision-making course in the Israel Defense Forces Command and General Staff College were asked to write cases of decision making under uncertainty based on personal experience (Lipshitz & Strauss, 1997). Based on these research results, the authors proposed the RAWFS (Reduction, Assumption based reasoning, Weighing pros and cons, Forestalling, Suppression) Heuristic Hypothesis that consists of quasi-normative processes for coping with uncertainty. Decision makers begin by trying to reduce uncertainty by collecting additional information; if this is not feasible, they use assumptions to fill gaps in understanding; they compare the merits of competing alternatives if such alternatives are available. Proficient decision makers may retain a back-up alternative to guard against undesirable contingencies or suppression (denial, distortion of undesirable information) may be used as a last resort. This model is compatible with various naturalistic decision-making models (Klein, 1993; Lipshitz, Klein, Orasanu & Salas, 2001).

In this section we reviewed three comprehensive cognitive concepts: SA, Sensemaking and NDM. These concepts, which developed during recent years, represent the efforts to gain better psychological understanding on how people operate in real-world situations, particularly, during the operation of complex, human-machine systems. As shown above, each of the concepts may contribute to the analysis and Comprehension of the C^3I environment. The more mature notions of SA and NDM have already yielded considerable relevant research; whereas, Sensemaking which is a very new and highly general concept, does not lend itself, so easily to generating research hypotheses. In the next section we examine, more closely, the nature of uncertainty in C^3I systems.

Uncertainty in C^{3}I information systems

In the previous sections we argued that C^{3}I information systems serve as representations of the real world, which commander cannot view directly. Inevitably, these representations are partial and their accuracy is limited.

Sorting uncertainty

Uncertainty has many definitions, Lipshitz & Strauss (1997) listed 14 different conceptualizations of uncertainty and similar terms (e.g., risk, ambiguity, turbulence, equivocality, conflict). Several definitions refer to the way decision makers conceptualize uncertainty (e.g., Anderson, Deane, Hammond & McClelland, 1981; Yates & Stone, 1992; Lipshitz & Strauss, 1997). However, one issue that is not clearly represented by most models is the level of awareness to the presence of uncertainty in the situation awareness display; Does the operator know whether the available information represents high or low levels of uncertainty?

In reality, the selection of coping strategies and the resulting decisions may be affected by the operator's awareness of uncertainty. According to Lipshitz & Strauss' (1997) coping strategies, if an operator is totally unaware of the level of uncertainty he/she may act as if they had consciously resorted to the suppression strategy. If, however, the operator is aware of uncertainty he/she may employ some more effective coping strategies. This issue can be viewed in terms of the knowledge driven approach, which argues that decision making in general is determined by operators' knowledge driven strategies, namely, action arguments that describe how decision makers manipulate domain specific parameters in order to achieve a certain goal (Lipshitz & Rozenbaum, in preparation). From a different perspective, one may ask how to reduce the gaps between actual and perceived quality of representations (displays) of the world (e.g., through indications of uncertainty or information quality).

For that purpose we propose two different sorting approaches for uncertainty in C^{3}I information systems.

Sorting by source: Uncertainty can originate from the sources of information, from the information display or from the limitations of the user. We propose to refer to the first two categories as *basic uncertainty.*

Sorting by levels: Sorting uncertainty according to its relation to the three levels of SA, Perception, Comprehension and Projection (Endsley, 1995).

Sorting uncertainty by source

Uncertainty the originates from technology and information sources

The combined sources of information that are represented in the C^3I information system and in other systems (e.g., verbal communication) are supposed to provide the commander with an accurate and comprehensive representation of reality. However, even the finest and most advanced acquisition systems cannot warrant full and accurate real-world information. Hence, gaps and inconsistencies between reality and displayed information are inevitable. The enemy intelligence picture may, without doubt, be a major source of *basic uncertainty* (see below for further analysis).

Uncertainty due to hardware and software limitations

Events take place in a large and highly complex real world, whereas, the C^3I information system is a small computer display system. The need to reduce the real world into such a limited device imposes many distortions. Feltovich, Spiro & Coulson (1997) described several reductive biases that may emerge when experts cope with tasks that require complex cognitive skills. Some of these mechanisms may also characterize the disparity between a complex real world and its reduced C^3I information system depiction.

- The world is minified to a reduced scale.
- Most of the time the three-dimensional world is reduced into two-dimensional views.
- Objects are displayed symbolically and not naturalistically.
- Most often objects have to be grouped into large units (e.g., battalions rather than single armored vehicles).
- When a high level of detail is required, it is necessary to "zoom in" and enlarge the image; as a result, only a small portion of the real world can be viewed at one time and the world is fragmented into a mosaic of small "snapshots."

- During the planning phase dynamic processes have to be fragmented into static samples.
- Real-world simultaneous processes, have to segmented and analyzed sequentially (e.g., because they take place in different locations).

Without going into the specifics of user interfaces, it is clear that inherent limitations of C^3I information systems may add significantly to *basic uncertainty*.

Uncertainty experienced by the commander

Commanders are affected by various additional factors that may degrade their decision-making beyond the level imposed by *basic uncertainty*. The commander may lack expertise, be unprepared for the current task, be vulnerable to stress, lack teamwork skills, be under or overly confident, etc.

Sorting uncertainty by levels of SA

C^3I information systems are sometimes referred to as 'Situation Awareness Displays (e.g., ISD Data AB, 2004), indicating that one of their major roles is to enable commanders to build and maintain SA. Hence, one may ask how well a system supports SA.

In general, C^3I information systems may be quite effective in providing and representing Perception level data and information, but less so in supporting the Comprehension and Projection levels of SA (Endsley, 1995). The reasons for this are twofold: first, technologically-driven acquisition systems acquire much *data,* little *information* and very little *knowledge* and *understanding* (Kuperman, 2001). Secondly, C^3I information systems are well designed for depicting basic, Perception level data but not so well adapted for depicting higher levels of information; i.e., even if high-level information exists, it may not be fully available to the user.

The "Perception level" of uncertainty

In previous sections we referred to "Perception" as pertaining to detection, recognition and identification of major features of relevant objects. This is somewhat similar to the 'data' and partially to the 'information' level as defined in the 'cognitive hierarchy' of the US Army (Kuperman, 2001). Given good information sources and effective distribution

systems, data may be quite comprehensive and accurate. Possible remaining sources of uncertainty are:

The picture is incomplete: not all elements are represented (e.g., elements that are hidden, do not emit radiation, etc.).

The picture is inaccurate: inaccuracy can stem from various sources - for example:

- Information is not up-to-date, data was updated 't' minutes ago.
- Various sources provide conflicting information.
- Data sources cannot provide accurate location information (e.g., direction is accurate but distance is not.
- Multiple data sources point to one object or to several closely located objects (possible under/over counting).
- Objects may be detected but not recognized (e.g., targets or decoys? alive or destroyed?).

The "Comprehension level" uncertainty

Comprehension (Endsley, 1995) requires that data are transformed into information and then into knowledge (in terms of the US Army cognitive hierarchy - Kuperman, 2001). In previous sections we referred to Comprehension as pertaining to the significance, intentions, and integrative aspects of relevant objects (e.g., to which unit does it belong).

Comprehension level information regarding friendly forces may often be obtained (based on self reports or identification: friend, foe or neutral capabilities, etc.). However, the comprehension level enemy's information may be very hard to acquire, because the adversary will do his best to hide and disguise it. What is the adversary's condition? Does he have sufficient supplies? Is the morale of the troops high? What are his intentions?

Furthermore, even if such information is available it may not be presented to the user in a straightforward and readily available manner.

The "Projection level" uncertainty

Projection (Endsley, 1995) is about the "where" and "what" of relevant elements in the near future. In terms of the US Army cognitive hierarchy (Kuperman, 2001), it is related to 'understanding'.

At this level the commander may experience some uncertainty in regard to friendly forces (Do they follow the plan? Have they reported as scheduled?) and much uncertainty regarding the adversary (Will the forces continue in the same tracks? Will they act according to their doctrine? Is the received information real or a deception?). Again, even if the information exists it may be difficult to represent on the C^3I information display.

The specification of *possible courses of action* of the adversary represents the efforts that are routinely made by commanders to reduce uncertainty by anticipating plausible alternatives and preparing for each of them (i.e., "branch" or contingency planning).

Coping with uncertainty in C^3I information systems

The question is what can be done in order to reduce *basic uncertainty* in C^3I information systems and, particularly, how to diminish its negative effects. Three possible approaches are proposed:

- The information that is represented in the C^3I information system can become more comprehensive, more up-to-date, more accurate, etc.
- The information can be depicted in a clear and readily available manner and adapted to the missions and to the needs of the users.
- Various decision support systems may be introduced (e.g., Morrison, Kelly, Moore, & Hutchins, 1998).

Improving information quality and representation

As indicated above, C^3I information systems serve as partial representations of real-world events. A more comprehensive and more accurate representation may reduce *basic uncertainty*. Various ongoing projects are aimed as improving the technologies that acquire, distribute and display battlefield information (e.g., The USAF Cyber Warrior, Kuperman,

Whitaker & Brown, 2000; DARPA's Carnegie Melon University (CMU) - command post of the future; Lockheed Martin FIOP system; US Marine Corps MAGIS system; US Army C^4I programs). The details of such projects are not in the scope of the present research; instead, we briefly review how technical improvements may contribute to SA, Sensemaking and decision making of C^3I information system users.

Supporting Situation Awareness

Endsley's (1995) definition of SA refers to Perception, Comprehension and Projection of future status of relevant elements, within a volume of time and space, each of these components should be represented in the C^3I information systems.

<u>The representation of space</u>

Real battlefield events take place in space. Basically, C^3I information systems represent space as a miniature two-dimensional entity. Based on these representations, commanders need to understand real space, visualize it and run imaginary scenarios in it (Serfaty et al., 1997). Several measures can be taken in order to facilitate the visualization of the world, e.g.:

- Use a variety of maps for the general overview and aerial photographs for improved visualizations of more specific details.
- Provide various static and dynamic visualizations in three-dimension, based on three-dimensional terrain data (DTM – digital terrain map), with the addition of data on human-made objects by overlay or superposition.

It should be noted that *basic uncertainty*, regarding space, may always remain high. Scale differences between the world and its representations are fundamental features of the C^3I information system; maps are rarely up-to-date, the saliency of aerial photographic features may depend on the season and time of day in which they were taken; the representation of human-made objects may be lacking (e.g., How does one represent the stories of high buildings in urban areas?); in addition, despite decades of research and development (e.g., ISD Data AB, 2004) the availability and effectiveness of three-dimensional displays (e.g., stereoscopic representations) is still very limited.

The representation of time

Time and timing may be one of the commander's major concerns during planning and during command and control (i.e., actual execution of the plan). In terms of SA (Endsley, 1995) while time represents an important component in both Perception and Comprehension it predominates in Projection. The timing constraints of a complex operation may be as difficult as the design of a railroad timetable and even more so (because trains are much more predictable than humans). Nevertheless, it may perhaps be possible to introduce planning support system into the planning modules of C^3I information systems. It may also be possible to animate proposed solutions in order to improve the visualization of the temporal elements and interactions of the plan.

However, since battlefield timing depends on human capabilities and motives, *basic uncertainty*, regarding timing, is bound to remain high.

Perception of elements

The ability to acquire, process, distribute and display information about relevant objects is constantly improving (e.g., Talcott *et. al.*, 2001). A distinction should be made, however, between friendly and hostile forces.

Theoretically, the data on friendly forces can be quite accurate. Precise localization systems (i.e., GPS) and effective communication networks can provide all network members with accurate and up-to-date information, regarding the location and identity of friendly forces and additional necessary data (e.g., supply status, technical problems).

The accurate picture of hostile forces (as well as neutral forces) is, obviously, a different matter. Many efforts are invested in developing and operating a variety of intelligence, surveillance, reconnaissance and damage assessment systems (e.g., US Marines Air Ground Intelligence System – MAGIS, 2003), some of which may, potentially, provide improved information.

The large diversity of means and devices (e.g., COMINT, SIGINT, IMINT, HUMINT) extends the ranges of time (e.g., day and night), space (e.g., land, sea, weather conditions, far and close domains), and type of data that may be acquired. Powerful computers enable the processing of the multitude of data into a potentially coherent picture.

The combined use of various devices may improve the ability to detect and recognize objects. For example, the concurrent use of TV, FLIR and SAR may significantly improve the ability to distinguish decoys from real targets (Brickner, Oettinger & Kuperman, 2002).

Image processing algorithms may assist a human observer (or replace him/her) in target detection and recognition (ATR – Automatic Target Recognition or Assisted Target Recognition; Cohen & Tolcott, 1992).

Still, even the most advanced armed forces may not be able to acquire a full, accurate picture of enemy forces:

- The adversary hides and camouflages his devices.
- The adversary refrains from emitting radiation thereby reducing his electromagnetic signature.
- The adversary uses decoys (e.g., the Serbians on Kosovo: Beaver, 1999).
- Elements are highly mobile and need to be sampled frequently for accurate location and status.
- Elements have very low signatures (e.g., small terror groups).
- Elements operate in a noisy environment (e.g., terror groups in a civilian environment).
- Conditions (e.g., weather) degrade the effectiveness of some acquisition devices, thereby reducing the completeness and accuracy of the picture as a whole.

Comprehension and Projection of elements

As indicated above, most C^3I information systems provide only little information to support the Comprehension and Projection levels of SA. Hence, Comprehension and Projection may be based primarily on the commanders' expertise and their ability to see beyond the data, combine and integrate information from various sources, recognize patterns and understand their operational meaning. This capability is required during mission planning as well as during command and control phases.

The C^3I information systems may support these efforts in various ways:

- Compensate for lack of expertise by presenting information supplements (e.g., procedures, target signatures). The usage of such information may, however, be beyond the real-time processing capacity of the operators (Pascual & Henderson, 1997).
- Provide updated intelligence, for example, COMINT and HUMINT may provide information regarding the adversary's conditions, e.g., Is he requesting reinforcement?
- Frequent intelligence updates, including closed cycle intelligence (e.g., information from a UAV) reduce uncertainty and shorten the necessary range of Projection. The commander may have to project only short term developments and may be able to validate his/her decisions and change them while it is still possible to influence their outcomes. The C^3I information systems may facilitate this process by rapidly displaying and distributing the necessary information.

Evidently, full and completely accurate Comprehension and Projection of enemy activities may not be possible.

Supporting Sensemaking

The basic ideas behind the concept of 'Sensemaking' are related to C^3I information systems. Network centric warfare links people with information to achieve greater decision making effectiveness; these people need a common operation picture, furthermore, they need a common Sensemaking framework for translating the common picture into actionable knowledge. The process, as a whole involves cognitive, social, organizational, technical and cultural dimensions (Leedom, 2002).

It may be argued that ineffective handling of uncertainty may hamper Sensemaking. Furthermore, different participants in the common operating pictures may work out different notions and develop different biases about uncertainty, thereby impairing common Sensemaking. Hence, reduction of *basic uncertainty* and more effective handling of *remaining uncertainty* may enhance Sensemaking.

As of now, few analysis and research tools have been developed for Sensemaking, although an initial attempt at this is being made by Klein, *et al* (in press).
We propose to examine how C^3I information systems can be designed to better serve the Sensemaking mechanisms as described by Klein, *et al.,* (in press), data/frame theory.

1. Sensemaking is the process of fitting data into a frame and fitting a frame around the data: the C^3I information system is supposed to provide the data within a frame of references that enhances its understanding. Even though Klein *et al*'s 'frame' is a cognitive concept, we may perhaps hypothesize that an appropriately designed information system may enhance framing and re-framing processes.
2. Data are inferred using the frame rather than being perceptual primitives: C^3I information systems stand the danger of presenting users with a collection of information primitives, rather than with "frames". If this is the case, then the C^3I information systems may not provide a readily available representation of the real world. The reductive distortions of Feltovich *et al* (1997) may provide some insights as to how these risks can be avoided. Continuous processes should be presented as continuous rather than as discrete steps (i.e., provide a continuous representation of a mission plan); dynamic processes should be presented as such and not as static representations (i.e., provide high refresh rates); simultaneous events should be available simultaneously and not sequentially (i.e., enable concurrent display of related events that are geographically distant); interacting processes should be identified and pointed out rather than overlooked (i.e., the interaction between friendly actions and enemy courses of action).
3. Data have to be distinguished from noise: *Basic uncertainty*, as defined above, can be described as a type of noise, hence, its reduction may serve the required purpose.
4. The frame is also inferred based on a few key data elements that serve as anchors: Anchors should be explicitly presented in the C^3I information system for orientation, navigation and Comprehension of the picture as a whole.
5. Sensemaking is used to achieve functional understanding (what to do) as well as abstract understanding: Clearly, both are necessary to the commander who has to take specific decisions while maintaining an overview of the situation as a whole. Good C^3I information systems must provide the general frame of reference for abstract understanding by also supporting the functional understanding.
6. Most of the mental models used by experts and novices are fragmentary. If this is indeed true, it is encombent on the designer the C^3I information system to represent the necessary variety of fragments and provide the user with the necessary flexibility

to combine the fragments according to changing needs. This permits a more general and more flexible approach than the representation of whole, complex mental models.

7. The nature of Sensemaking varies depending on whether we are trying to assess a situation, build a richer understanding, raise questions about our understanding or explain away discrepancies, compare different hypotheses regarding what may be taking place, or search for some explanation that can help us sort out what is going on: The representation of uncertainty (see below) may be important for each one of these processes, although the modes of presentation should be adapted to changing needs.

Information about basic uncertainty

As argued above, *basic uncertainty* will always exist in C^3I information systems. In addition, there may often be uncertainty about uncertainty. As a result, the system may mislead the operators to assume that the information is more complete or more accurate than it really is, or *vice versa* lead him/her to distrust valid data.

Known and unknown uncertainty

The status of data/information categories that are normally not represented in C^3I information systems (e.g., projection of future enemy status) may be intuitively obvious to the operator who does do not expect the display of such information. In contrast, there may be uncertainty in regard with the completeness and accuracy of categories that are displayed. This information may be related to time, space and, predominantly, to the objects' representations in supporting the commander's Perception, Comprehension and Projection of the situation.

Uncertainty about uncertainty may be of one or more of the following types:

Misses: Information that exists in the world, but is not represented by the C^3I information systems.

False alarms: Information that does not exists in the world but is represented by the C^3I information systems (i.e., noise) or irrelevant information that is depicted as relevant (e.g., decoy or destroyed targets displayed as valid/current targets).

Sources of inaccuracy: Inaccuracy can stem from various sources:

- Information has not been updated for some time; its current temporal or geographic accuracy is unknown.
- Inaccurate location: information was acquired by sources that do not provide accurate location (e.g., provide only direction).
- Unknown number of elements: various sources of information provide data about objects; it is unclear whether or not different sources indicate the same or different objects.
- Uncertainty in regard with the number of elements may also be caused by display clutter (i.e., inability to distinguish between possibly overlapping symbols of different objects).
- Unknown identity: objects may be detected but not identified (e.g., What type of object is it? Is it real or a decoy? Is it active or destroyed? Etc.).

System information about uncertainty

There are three possibilities regarding the system's status of uncertainty about uncertainty:

- The system has no information about uncertainty.
- The system has general information that may reflect on uncertainty. (For example, the general quality of target acquisition sensor data in a specified area is low due to weather conditions.)
- The system has specific knowledge of uncertainty, for example:
    - The time of the last update is known.
    - The size of location error due to limitations of the acquisition system is known.
    - Different acquisition systems provide signals from the same area. The system knows that it is unable to decide whether to display a symbol for one target or for more than one target.
    - There is uncertainty regarding recognition / identification of the detected entity (e.g., information suggests to a 60/40 percent probability that the object is of type X/Y respectively).

Display of information about uncertainty

Essentially, it is possible to provide the operator with information about known sources of *basic uncertainty*.

General information about uncertainty can be displayed in various forms, e.g.:

- General notes indicating permanent or temporary weaknesses or malfunction of acquisition, processing or distribution systems.
- Verbal or graphical indications of areas, types of objects, etc., for which information is unreliable.

Specific information about uncertainty can be indicated by various means, which have to be adapted to the type of *basic uncertainty* as well as to the needs and working processes of the users. Some possible examples are:

- There may be a digital (e.g., time readout) or graphical (e.g., fading color) indicating the time since the last updates of information.
- Circles may indicate the range of uncertainty of object location (e.g., the target location error probability curve depicting the 50% level of confidence in location accuracy).
- Symbols that represent either different objects or multiple representations of the same object can be indicated by a connecting line.
- The level of system confidence in objects' identity can be indicated.
- Objects that are suspected as decoys, destroyed targets, etc., may be so indicated.

Should basic uncertainty be indicated?

The pros and cons of this question are discussed in the next section.

Coping with basic uncertainty

If the operator is aware of *basic uncertainty*, he/she may try to cope with it and prevent its negative effects.

Pros of representing basic uncertainty

The aware operator may employ one of the first four coping techniques as outlined by Lipshitz & Strauss RAWFS model. Decision makers begin by trying to reduce uncertainty by collecting additional information (Reduction); if this is not feasible, they use assumptions to fill gaps in understanding (Assumption-based reasoning); they compare the merits of competing alternatives if such alternatives are available (Weighing pros and cons). Proficient decision makers may retain a backup alternative to guard against undesirable contingencies (Forestalling). For example:

- If it is known that the location of a target is approximate, the commander may issue a reconnaissance mission (i.e., Reduction).
- If the picture of a specific area is known to be inaccurate, the commander may act upon assumption based reasoning but also take special precautions and retain a backup alternative (i.e., Forestalling).
- The higher the level of *basic uncertainty*, the more it is important to retain backup alternatives and compare their merits (i.e., weighing pros and cons).
- Essentially, if the level of uncertainty is known, it is possible to avoid Suppression (which is a destructive option).

Cons of representing basic uncertainty

The display of additional information, regarding uncertainty, may sometimes be destructive. Flach & Kuperman (2001) indicated that humans may be overwhelmed by the complexity of the interface and become hostages of technology if it is not based on sound Cognitive System Engineering (CSE) principles. More specifically:

- More data increases workload, aggravates clutter and may interfere with the main task. For example, Pascual & Henderson (1997) observed that commanders were unable to use the Standard Operating Procedures of the British Army during the command and control process and could benefit from it only if they mastered it before hand.
- In the battlefield certainty cannot be achieved. Schmitt & Klein (1996) argued that information technology may not provide the real solution to uncertainty and that the quest for certainty may be paralyzing, rather than constructive.
- Information may not be constructive; the operator may not know what to do with it and may be faced by more alternatives that he/she can handle (Lipshitz & Strauss, 1997).
- Additional information may not fit into the operator's data frame (Klein, *et al*, in press) and may not contribute to the construction of an alternative frame.
- Given that levels of *basic uncertainty* are addressed by the system, the operator may now assume that everything is under control, whereas, the "picture" may still be partial.

The general conclusion is that there is a delicate balance between the need for information on the quality and reliability of C^3I information display and the need to refrain from

overloading commanders and their staffs with additional, potentially confusing, information. The latter conclusion holds not only for information about *basic uncertainty* but for all types of C^3I information (i.e., simple C^3I information systems are sometimes more useful than highly sophisticated ones).

Attenuate the consequences of basic uncertainty

After the reduction of *basic uncertainty* to a possible minimum, it is necessary to try to avoid the negative consequences of remaining uncertainty. Serfaty *et al.*, (1997) analyzed decision making processes in the C^3I environment and specified two major means for attenuating possible consequences of uncertainty: robustness and flexibility.

Robustness

An operational plan is robust if it is not too vulnerable to uncertainty. Robustness can be achieved in various ways.

- Simplicity: simple, straightforward modes of action are more robust than complex, intricate modes; fewer steps and fewer components provide fewer opportunities for error and improve the overall probability of success.
- Effective planning: an effective operational plan can contribute to robustness:
    - Using effective tools to plan and verify correct timing.
    - Using means (e.g., real or virtual sand [table] model) for the creating and examination of possible courses of enemy action and preparing alternative responses.
    - Enabling the creation and testing of "local" possible courses of action, i.e., handling mission segments rather than the mission as a whole, thereby focusing on selected parts and solving specific problems.

Flexibility

Flexibility is the ability to adapt plans and modes of action to changing circumstances.

- Continuous or frequent updates: If a commander can receive reliable intelligence updates at any given moment, then his/her decisions may be adapted to changing circumstances, thereby avoiding the development of large errors. In such case it may be

best to act upon a fairly general plan and supplement the specifics at near real-time, during the command and control phase.

- Flexible planning: good planning (even general planning) may relieve workload and stress during the real-time command a control phase. The preparation of possible courses of action, including the specification of checkpoints and criteria for the selection of an alternative plan, may be very helpful.

Flach & Kuperman (2001) view 'flexibility' as contrary to 'rigidity' on a scale of robustness. In the information warfare arena, flexibility characterizes formal systems, in contrast with the rigidity of automatons. The authors suggest that experts' performance may provide insights as to what attributes of the system make a difference. Experts are characterized by fast and flexible decision making capabilities. Research in various fields of expertise (e.g., tactical situations - Kobus, Proctor, Bank & Holste, 2000) shows that experts generate high-quality alternatives very early (often as the first option considered), thereby maintaining flexibility and robustness. The use of experts' performance as a model is in line with the general view of NDM (Klein, 1997).

Summary

In the present section we proposed two different methods for sorting types of uncertainty in C^3I. Sorting by source technological (acquisition, processing, and display systems), or user related sources, where system related sources are defined as *basic uncertainty*; or, sorting by level of SA (Perception, Comprehension or Projections). Then we analyzed various methods of coping with uncertainty, focusing primarily on *basic uncertainty*. *Basic uncertainty* may sometimes be reduced by improving information quality and representation techniques. Figure 3 which is a revised version of Figure 2, depicts some of these notions.

Only parts of real-world information are acquired by various systems, the gap between the whole and the part constitutes one source of *basic uncertainty*. The acquired information is processed and disseminated. This information contains primarily sources of *data,* some *information*, little *knowledge* and practically no *understanding* (Kuperman, 2001). Information is represented by a limited C^3I information system, the short comings of which represent another source of *basic uncertainty*. The information that is presented to the

commander or command team may provide strong support for SA at the Perception level, but much weaker support for Comprehension and Projection. SA processes. Decisions are based on available information. The major research question is how to attenuate the negative effects of uncertainty. More specifically: How to deal with information about uncertainty? Should it or should it not be presented to the operator? What methods can be used to attenuate the negative effects of *remaining uncertainty*.

In the next (and last) section, some ideas for further research, focusing on the representation of uncertainty, are outlined and briefly discussed.

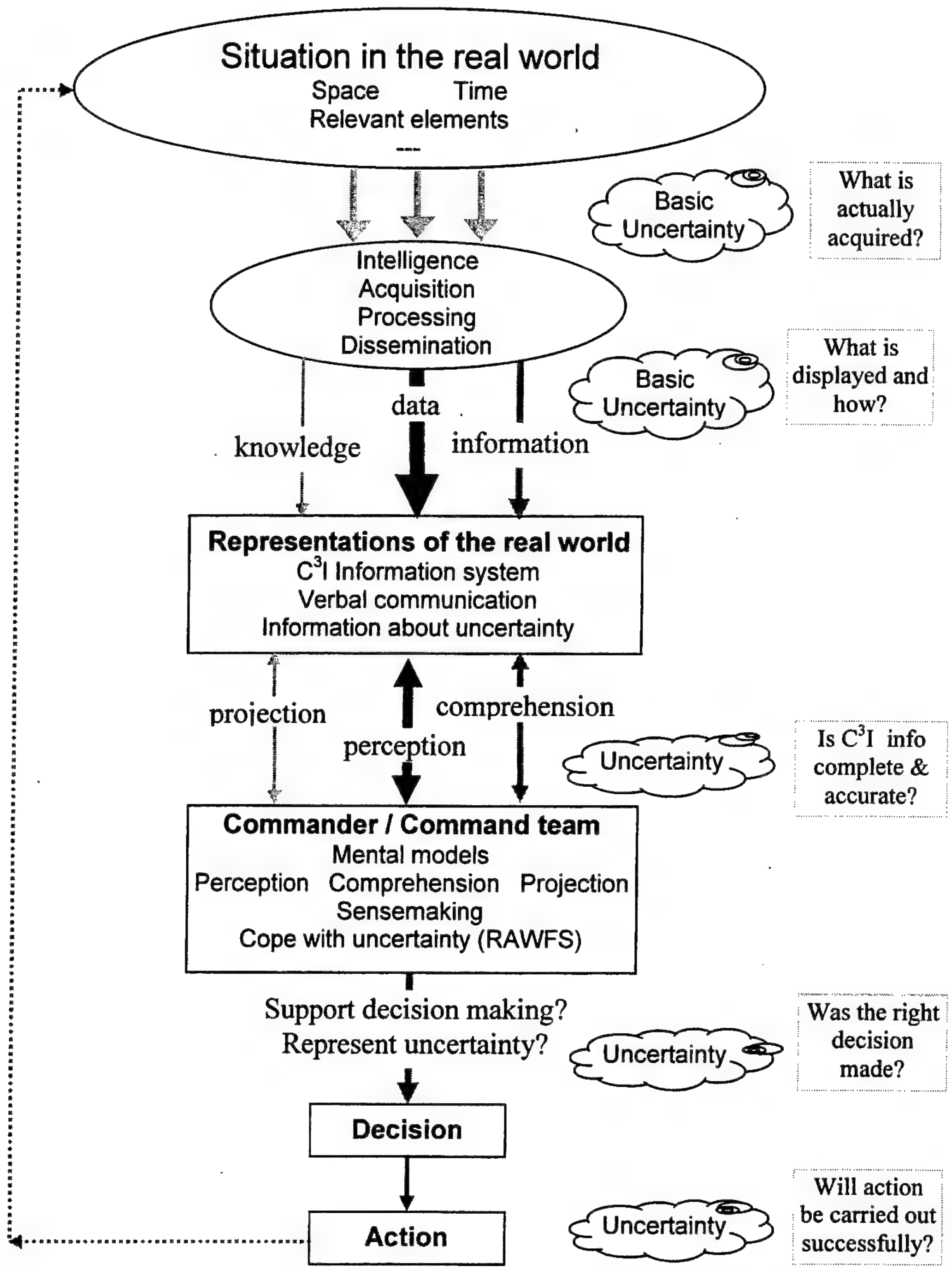

Figure 3: The figure is a revision of Figure 2. Information flows from the world to the C^3I system and to the commanders who make decisions and take actions. As information passes between sources it is reduced, limited and distorted, as represented on the connecting arrows (see text above for further interpretation). The width and darkness of the arrows schematically represent the relative quantity and reliability of information.

Further research

It is proposed to focus further research on the issue of representation of *basic uncertainty* and coping with remaining uncertainty.

It is proposed to create a micro-world and a simulated C^3I information system that would serve as a research environment for testing various potentially relevant conceptualizations. At later stages it may be possible to validate some of the more advanced notions during real military exercises.

First we suggest testing the proposition that Endsley's (1995) classification of situation awareness can serve as a foundation for identifying different types and levels of uncertainty in C^3I systems. Measures of SA (e.g., SAGAT, Endsley, 2000; or more dynamic approaches – Miller & Shattuck, 2004) can be used to diagnose the various types and levels of uncertainty. These could then serve as a baseline for the testing of various strategies for coping with uncertainty and in particular, for testing various types and levels of representation of uncertainty (i.e., Does information about uncertainty improve SA?).

Secondly, it is proposed to test the descriptive validity of the data/frame notion (Klein, et al., in press); Does the presence or absence of information regarding uncertainty affect the nature of frames and framing/reframing processes? Specific tools for the testing these issues have not been developed yet and may have to be prepared as part of the research effort.

Thirdly, the effects of the representation of uncertainty on coping strategies will be tested; how does the nature of C^3I information affect the selection of each of the RAWFS coping strategies (Lipshitz & Strauss, 1997), e.g., Does overestimation of the quality of information lead to the use of repression strategies? The selected strategies will be sorted based on the analysis techniques used by Lipshitz & Strauss, (1997).

The combined, overall product of this research should provide a comprehensive conception on the issue of representing uncertainty in C^3I information systems and insights regarding coping strategies and techniques. In addition, the ability to use exiting measures of effectiveness (i.e., SAGAT), heuristics (i.e., RAWFS) and theoretical concepts (i.e., data/frame) will be extended and tested.

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GLOSSARY

ATR	Automatic / Assisted Target Recognition
BDT	Behavior Decision Theory
C^3I	Command, control, communications and intelligence
CDM	Classical Decision Making
CMU	Carnegie Melon University
COMINT	Communication Intelligence
DTM	Digital Terrain Mapping
FBCB2	Force XXI Battle Command Brigade and Below
FIOP	Family of Interoperable Operational Pictures
FLIR	Forward Looking Infrared
GPS	Global Positioning System
HUMINT	Human Intelligence
IMINT	Imagery Intelligence
JDM	Judgment Decision Making
MAGIS	Marine Air Ground Intelligence System
NDM	Naturalistic Decision making
ODM	Organizational Decision Making
RAWFS	Reduction, Assumption based reasoning, Weighing pros and cons, Forestalling, Suppression
RPD	Recognition Primed Decision
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
SAM	Surface Air Missile
SAR	Synthetic Aperture Radar
SIGINT	Signal Intelligence
UAV	Unmanned Air Vehicle

Appendix A

Pilot Study: System Model of Situation Awareness and Decision Making in Command & Control - Workplan

Interim Report

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Raanan Lipshitz

June, 2003

Introduction

The objective of the present study is to develop a theoretic system model of command and control (C^2) situation awareness (SA) and decision making under uncertainty, suitable for guiding the planning and design of operator-in-the-loop (OITL) studies.

The program is divided into three phases. The first phase, summarized in the present interim report, presents some of the main concepts that will be elaborated and developed during the next stages. The second phase will focus on a literature survey of related subjects. The third and final stage will identify a set of candidate measures of effectiveness (MOEs) for "sensemaking" in C^2. Based on these MOEs, criteria for a model of decision making under uncertainty, which supports situation assessment, will be proposed. Recommendations for testing, enhancing, or extending existing models will be made.

Information in C^2 operations

Information is one of the most important assets in the battlefield. The side that is capable of acquiring, handling and protecting its information, while denying reliable information to its adversary, may win the information war.

Builders, Banks and Nordin (1999), noted that existing models of C^2 are a variant of a cybernetic approach which describes the C^2 processes within the framework provided by control theory or mechanical-electrical communication theory. Well known examples are the Lawson model. Wohl's SHOR model (from Builders, et. al, 1999) and most familiar, Boyd's (1987) OODA (Observe-Orient-Decide-Act) Loop model. Kuperman (2001) indicates that Boyd's model is essentially human centered,

particularly in the *orient* node in which data, from various sources are collected, transformed, integrated and fused in order to establish the basis for situation assessment. Kuperman (2001) defined situation assessment as follows: "*Situation assessment is essentially an alignment of association of the observed data in the context of the situation*" (p. 231). Situation Assessment relies to a great extent on situation awareness (SA) and "sensemaking" processes and provides the foundations for decision-making (see Figure 1 below). Consequently, it is important to understand the roles that SA and sensemaking play in the C^2 decision-making environment.

The "Information world"

We propose the term "information world" to describe the combined sources of information available to an operator or a team of operators in typical missions. If the mission is decomposed into "situations", partial groups of elements may receive different weights during different situations (reflecting the changes in mission priorities from phase to phase).

The information world of a commander or controller in a C^2 situation will be further elaborated during the later stages of this study. The following (Table 1) are examples of possible components in the information world of an operator or a team of operators, in a C^2 center of an air component command.

Table 1: Example of the "information world" in a C^2 aerial strike center.

Category of Information	Examples / activities	Modes of representation
Geographical space		Maps, aerial photos
Terrain	Mountain, hills, desert	Maps, DTM[1]
Airfields	Takeoff & landing	Maps, aerial photos, verbal communication
Targets	SCUD missile launchers	Symbols on maps, aerial photos, sensor imagery, verbal reports
Threats	SAM	Symbols on maps, aerial photos, verbal reports
Friendly forces	Ground forces	Symbols on maps
Atmospheric conditions	Lighting, visibility	Weather report
Aerial space	Flight route limitations	Symbols on maps, Verbal reports
Controlled forces	Location	Symbols on maps, radar
Other friendly forces	Close support force	Symbols on maps, radar
Hostile, threats	Enemy fighter aircraft	Symbols on maps, radar
Controlled forces (status)		Digital information, verbal reports
Status	Mission stage	Digital information, radar, verbal reports
Aircraft condition	Fuel, malfunctions	Verbal reports
Pilot condition	Expertise, fatigue	Prior knowledge, verbal reports

Representations and mental models

The information world that impacts the decision maker is not a mere collection of various pictorial, graphical verbal and acoustical artifacts. Rather, decision makers construct out of these elements organized structures of information that can be roughly referred to as *mental models* (Lipshitz & Ben Shaul, 1997).

In order for a C^2 display to be effective it must first provide the operator with the necessary information and secondly, it has to present it in a way that is compatible with the user's existing mental model (Wilson & Rutherford, 1989). For example, it

[1] DMT = digital terrain map

seems reasonable to assume that for inherently spatial situations in which the mental model may have strong spatial features, a visual / spatial display may be most useful. For example, Mogford (1997) suggested that the mental model of air traffic controller's comprises two components, a *domain model* which encompasses a mental picture of the airspace and the controlled aircraft and a *device model* which represents the understanding of various devices and instruments. The different representations of these two mental models should lead to different types of displays, a spatial display of the airspace and a combined alphanumeric and graphic display for the device model.

The world-image as represented in the mental model may be envisioned from various viewpoints (e.g., Wickens, 2000; Wickens & Prevett, 1995). One important distinction is between the "ego reference", in which the operator views his or her own body as the center point of the image (e.g., a commander may visualize himself in the front seat of the leading aircraft), and various possible outside views (e.g., "god's eyes view", diagonal views). The actual ways in which operators imagine the world are of central importance, as they may reflect on the desired ways of displaying representations of the world (Wickens, Thomas & Young, 2000; Leedom, 2001).

Situation awareness

The concept of situation awareness (SA) as defined by Endsley (1995) "*the perception of the elements in the environment within the volume of time and space, the comprehension of their meaning and the projection of their status in the near future*" is predominantly useful for the description and analysis of spatial situations. The association between SA and mental models has been discussed by many researchers (e.g., Endsley 2000; Bolstad & Hess, 2000). In recent years the notion of SA have been extended to include teamwork and team SA (Endsley & Jones, 2001) in team work

Sensemaking

Sensemaking is a rather vague concept that can be viewed as an extension of SA, to include knowledge and various meta-cognitive aspects that are not well covered by Endsley's (1995) definition of SA.

Weick (1995) provided a multitude of definitions applied to sensemaking in the social science literature and then proceeds to develop a number of basic properties of the sensemaking process. In particular, Weick (1995) emphasizes the role of enactment in

sensemaking, which is deciding and acting upon the environment as distinct from just interpreting it. These basic properties may serve as useful frameworks for sensemaking research in military C^2 (Leedom, 2001).

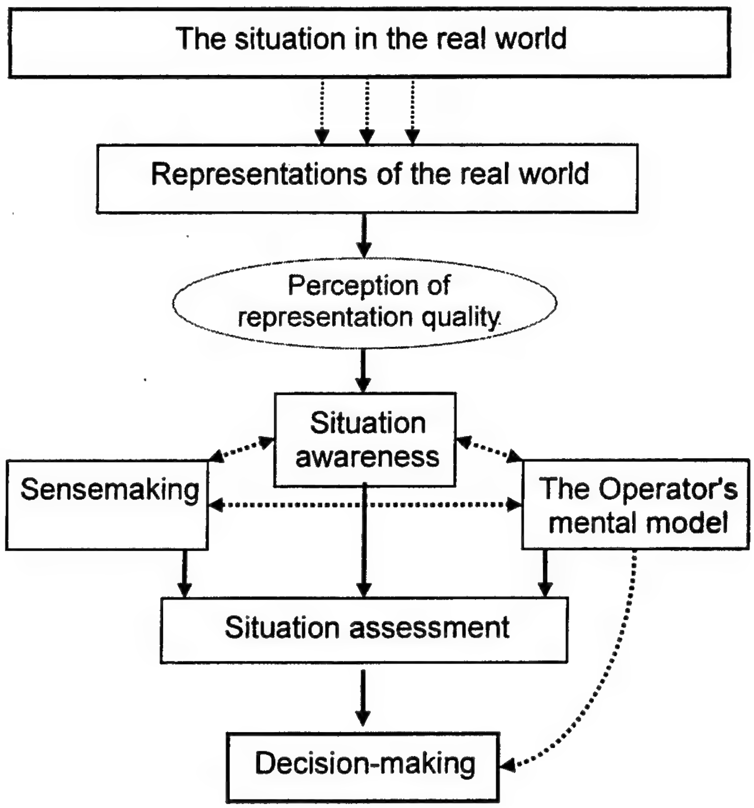

Figure 1: The flow of information processing and decision making in a C^2 environment

<u>**Summary**</u>

Whether *world image, mental models, visual thinking, SA* and *Sensemaking* are cognitive realities or just metaphors, they are useful notions for conceptualizing, analyzing and portraying some of the undergoing processes through which the operators cope with C^2 situations and make decisions.

Figure 1 depicts the relations between the "real" situation in the world, its various visual and verbal representation (displays), SA, sensemaking, the mental model of the operator and situation assessment, that lead to decision-making. The mental model is based primarily on prior experience and expertise. SA and sensemaking are interrelated to the mental model and rely on the information extracted from the various representations of the world. Finally, decision-making is based on situation assessment but is also related to the mental model and to the operator's perception of the representation (i.e., awareness to the quality of information).

Two main criteria determine the quality of the *representations* of the real world. First, they must provide a high fidelity representation of the real world and, second, modes of presentation must be compatible with the mental model in order to be readily available to the user. Hence, the quality of SA, sensemaking, situation assessment and decision making, depend on both these measures (fidelity and compatibility).

Complexity and uncertainty

The role of uncertainty in the battlefield was identified long ago. The German general Helmuth von Moltke (1848 – 1916) wrote, prior to World War I

> "*The problem is to grasp, in innumerable special cases, the actual situation which is covered by the mists of uncertainty, to appraise the facts correctly and to guess the unknown elements, to reach a decision quickly, and then to carry it out forcefully and relentlessly.*" (In: Hughes, 1993 p. 138).

Since Motlke's times, the means for acquiring C^2 information have evolved and improved. Information is acquired through various types of sensors (e.g., sensor imagery, ELINT, COMINT, etc.). The information is screened and processed by powerful computers, distributed through secure, broadband communication lines and presented on high-quality computer screens and sensor imagery displays. This does not imply, however, that contemporary commanders and controllers have an easier task than did their predecessors. On the contrary, these operators must cope with ever growing levels of complexity and uncertainty of the battlefield.

Complexity is roughly determined by the number of relevant entities in the real world and in their representations (displays). The larger the number of relevant entities, the higher the level of complexity. Complexity of the modern battlefield is growing because of the deployment of larger and more diverse forces and due to the vast extension of C^2 ranges.

In probability theory, uncertainty is the complement of probability, i.e., the smaller the probability of an event, the higher its uncertainty. In the C^2 environment uncertainty is growing as a function of complexity, as a result of the enhanced mobility of weapon systems (e.g., mobile air-to-air and air-to-ground missiles) and due to the growing use of camouflage, decoys and other countermeasures (Brickner, Oettinger & Kuperman, 2002).

Coping with Uncertainty

Lipshitz and Strauss (1997) defined uncertainty, as "a sense of doubt that blocks or delays action". Using this definition, they identified three principal forms of uncertainty in retrospective reports on decision making under uncertainty: inadequate understanding (a sense of having insufficiently coherent situation awareness), lack of information (a sense of incomplete, ambiguous or unreliable information) and conflicted alternatives (a sense that available alternatives are insufficiently differentiated). In addition Lipshitz and Strauss identified five principal strategies of coping with uncertainty: reducing uncertainty (e.g., by collecting additional information); assumption-based reasoning (filling gaps in firm knowledge by making assumptions that go beyond directly available data); weighing pros and cons (of at least two competing alternatives); forestalling (developing an appropriate response or response capabilities to anticipate undesirable contingencies); and suppressing uncertainty (e.g., by ignoring it or by relying on unwarranted rationalization). Other researchers have also proposed similar lists of coping strategies (e.g., Klein, 1998).

Based on their research results, Lipshitz and Strauss propose the RAWFS[2] Heuristic Hypothesis that consists of quasi-normative processes for coping with uncertainty. Decision makers begin by trying to reduce uncertainty by collecting additional information; if this is not feasible, they use assumptions to fill gaps in understanding; they compare the merits of competing alternatives if such alternatives are available. Proficient decision makers may retain a back-up alternative to guard against undesirable contingencies or suppression (denial, distortion of undesirable information) may be used as a last resort. This model is compatible with various naturalistic decision-making models (Klein, 1993; Lipshitz, Klein, Orasanu & Salas, 2001).

One issue that is not represented by decision-making models, including the Lipshitz & Straus (1997) model, is the level of awareness to uncertainty; does the operator know whether the available information represents high or low levels of uncertainty? The first four coping strategies seem to assume that the operator is aware of the level of uncertainty and seeks ways of coping with it, whereas, the fifth strategy assumes that uncertainty is somehow ignored or suppressed. In reality, however, the selection of

[2] RAWFS - Reduction, Assumption-based reasoning, Weighing pros and cons, Forestalling, and Suppression.

coping strategies and the resulting decisions may be affected by the operator's awareness of uncertainty. If an operator is totally unaware of the level of uncertainty he or she may act as if they had consciously resorted to the suppression strategy. If, however, the operator is aware of uncertainty he or she may choose to cope through one of the other strategies. This issue can be viewed in terms of the knowledge driven approach, which argues that decision making in general is determined by operators' knowledge driven strategies, namely, action arguments that describe how decision makers manipulate domain specific parameters in order to achieve a certain goal (Lipshitz & Rozenbaum, in preparation). From a different perspective, one may ask how to reduce the gaps between actual and perceived quality of representations (displays) of the world (e.g., through indications of uncertainty or information quality).

Sources of uncertainty

In the C^2 environment there are many sources of uncertainty. In the present study, the focus of interest is on uncertainty about the real world situation as reflected in its representations (displays). Uncertainty may result from missing or deficient information and also from poorly displayed and poorly organized information, i.e., information that exists but for one reason or another is not readily available to the user.

Examples of uncertainty

Some typical examples of uncertainty pertain to the following information:

- The existence (or non-existence) of an object or feature.
- The exact location and position of the object.
- Its properties.
- Its status, activity and capabilities.
- Its intentions.

Frequently, uncertainty may be attributed to data collection mechanisms or systems, for example:

- Data has last been updated 't' minutes ago (known or unknown latency).
- Various sources provide conflicting information.
- Data source cannot provide accurate location information.

- Multiple data sources indicate one object or several separate objects (possible under/over counting).
- Information regarding properties, status, capabilities or intentions is missing.
- The relations between features are unknown (e.g., does the existence of N objects indicate the existence of a unit?).

Measures of effectiveness

The third and final stage of the present study will identify a set of candidate measures of effectiveness (MOEs) for SA and "sensemaking" in C^2. Based on these MOEs, criteria for a model of decision making under uncertainty, which supports situation assessment, will be proposed.

Various direct and indirect measures may be evaluated as potential candidates: Task performance measures (i.e., action taken), direct assessment of decisions (e.g., Lipshitz, Strauss, 1997), direct assessment of SA (e.g., SAGAT, Endsley, 2000), subjective assessment of SA (e.g., SART, in: Jones, 2001), simulation studies (e.g., Guerty & Tirre, 2001), war games (e.g., Lipshitz & Rozenbaum, in preparation).

The various types of measures will be reviewed and evaluated during the next stages of the study. Recommendations for testing, enhancing, or extending existing models will be made.

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